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PRODUCTION OF ELECTRICALLY HEATED GLOVES

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Uniroyal Consumer Products

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This report describes two methods of fabricating electrically heated gloves; one using a patented hand constructed unique method and the other being a low cost easily reproduceable automated technique. Both of these methods use wire as the heating elements.

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FOREWORD

The well-known difficulty that is encountered in protecting the hands against the cold can be explained by the fact that the hands cannot be kept warm in arctic environments except by:

a. Maintaining a rapid circulation of blood (by exercise)

b. By withdrawing the hand and arm inside the clothing

c. By artificial heat.

For the man whose duties require him to be inactive, yet accomplish tasks requiring handling of cold objects with manipulatory skills for extended periods of time, the conventional means of hand protection appear to have reached their limitations, both in circumference of the handwear which can be used and materials suitable to supply the necessary insulation.

In view of these limitations, unconventional means of providing heat to the hands were investigated by Mr. Herman Madnick, Handwear Specialist for the U. S. Army Natick Laboratories. Under the auspicies of these same Laboratories, UniRoyal, Inc. was contracted to reproduce a glove technique previously developed for these Laboratories and at the same time investigate an alternate method to produce a lower cost wire heater glove which would still provide uniform heat to the hands.

The approaches discussed in this report are two of several approaches currently being investigated.

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INTRODUCTION

In 1969, 12 pairs of electrically heated gloves were produced for field evaluation, based on development work previously performed under contract #DAAG-17-67-C-0180, completed in July of 1968, as covered in Technical Report 69-33-CM.

The primary purpose of this present contract was to manufacture an additional 64 pairs of gloves, using the same method for producing the glove heater, incorporating an improved insulated leather outer shell.

It was recognized that this method, while producing a satisfactory serviceable product, entailed a great deal of highly skilled hand labor and thus was costly. Therefore, a secondary phase was included in the contract to explore alternate methods that would be more applicable to mass production, and if such a method proved viable, to produce 12 pairs of gloves for testing.

The technical manufacturing details are therefore separated in two parts: Phase I - manufacturing 64 pairs of gloves by the known developed art; Phase II - the development and manufacturing of 12 pairs by an alternate method.

INITIAL EVALUATIONS, STUDIES AND CONCLUSIONS

I. It was readily apparent that any alternate method would require a soft, flexible, insulated resistance wire. Therefore, initial development efforts were in this area. Previous studies proved that softness and flex durability of filament stranded wire could be achieved only by the use of extremely fine metal filaments. The bending radius at which the yield point of any filament is reached is approximately thirty times its diameter. Therefore, the resistance wire previously used was a fine hairlike 0.0008 inch diameter filament, with 49 filaments used together to provide 25.5 ohms per foot resistance. The final 49 strands of silk covered wire measured 0.007 inches in diameter. The break strength was approximately four pounds pull. This low tensile strength made it impossible to extrude an insulating coating over the wire.

II. One of the alternate methods contemplated at this time involved machine knitting the resistance wire to form a glove insert. It was determined that the insulated wire should not exceed 0.027 inches in diameter and have a tensile strength of not less than seven pounds in order to stand a knitting operation. In addition, it would have to stand knotting as well as repeated flexing.

Studies led to the ultimate use of tinsel wire to solve the problem. A 0.003 inch diameter wire was spiral wound around a stranded polyester core of 0.014 inch diameter. The core provided a break strength of eight pounds. The effect of spiral winding greatly increased the flexing durability since the spiral has a spring action when the core is flexed. The spiral wound wire thus does not take the sharp radius when flexing and the elastic limit theory does not apply. Samples of the wire were originally dip coated and flexed at a 0.15 inch radius 180 degrees 300,000 cycles without failure, and the wire was adopted for use. The number of spirals per foot were regulated to equal the 25.5 ohms per foot resistance required.

Further advantages to the use of tinsel resistance wire proved to be:

1. Availability - being a standard product, delivery of 2 to 3 weeks was obtained.

2. Circuity design - resistance in ohms per foot can be easily controlled by the spirals per foot of a selected resistance wire wound on a core by the manufacturer.

3. Low cost - approximately $15.00 per pound yielding 11,000 ft. of wire per pound.

The fine stranded wire previously used is made to order, and latest costs were in the $500 to $600 per pound range (24,000 ft. per lb.) and deliveries exceeded 6 months.

III. The most time consuming operation in the original molding manufacturing process that was to be used to manufacture the 64 pairs of gloves, was making the lead connections to the 15 circuits (30 connections). The resistance wire being of a very small diameter (0.007 inches) had to be built up with epoxy solder to a diameter approximately equal to that of the lead-in wire (0.036 inches) in order to make positive connections. Since a cover plate with 25 tons per square inch pressure exerted on it was used in the molding operation, coupled with the fact that the two lead-in wires had to repeatedly cross each other for alternate (+) and (-) connections, it was originally decided that since the cover plate would exert too much pressure on the crossed lead-in wires, the connections of the lead-in wires to the glove heater circuits would be performed as a post operation after molding.

Further studies in mold design indicated that if the insulated lead-in wires were to cross each other beyond the end of the mold proper, and grooves be made in the mold to receive the wires, molding pressure would not be brought to bear on the lead-in wires, and it should be possible to make the connections internal to the hand wiring of the resistance wire in the mold. By selecting a stranded lead-in wire that was insulated with teflon, which readily acted as "push-back" insulation, facilitating baring the insulation at the desired points along the wire where the 18 connections had to be made, the concept eventually proved practical. The detailed manufacturing method outlines the exact method used.

PHASE I - 64 PAIRS OF GLOVES

BASIC EQUIPMENT USED FOR WIRING, MOLDING AND FORMING GLOVE HEATERS

1. Mold - sketch #1 in appendix.
2. Electrically heated 2 platen hydraulic press capable of 35 tons per square inch pressure.
3. Direct current ammeter monitoring amps of current flowing through glove heaters.
4. Direct current ohm meter.
5. Direct current variable voltage power source.
6. Stretch and annealing board. Sketch #2 in appendix.
7. Cold box, $0^{o}F$ temperature.
8. Oven, $160^{o}F$ temperature.
9. Soldering iron.
10. Curved lacing needle.
11. Porcelain glove forms, sizes 7-8-9-10.
12. Heat lamp.

MATERIALS AND SUPPLIERS

	Material	Supplier
1.	Resistance wire 0.014 total gauge. 0.003 inch diameter phosphor bronze alloy (American Brass Alloy #518) Spiral wound on polyester core. 25.5 ohms/ft. resistance.	Designated as R-3341 from the Montgomery Co., Windsor Locks, Conn. 06096
2.	Lead-in wire - AWG 24 wire consisting of 19 strands of #36 AWG silver plated copper wire with a nominal 0.010 inch wall of TFE extruded insulation. Meets spec. MIL-W-16878-Type E (Navy Spec.) Supplier catalogue #1936 TX10 Type E, 600V AWG 24.	Tensolite Div. of Carlisle Corp. West Main St. Tarrytown, N. Y. 10591
3.	Thermoplastic Polyurethane Sheeting. 0.005 gauge #MP-2080 Black. Durometer - shore A scale = 75. Tensile (PSI) = 4000. Modulus @ 300% = 1100. Elongation @ break = 610. Specific gravity = 1.14. Melting point = 230^o to 280^o. Brittle temp. = -85^oF (no break).	Stevens Molded Products Co. Easthampton, Mass. 01027
4.	Thermoplastic Polyurethane Sheeting 0.025 gauge clear. Same specifications as in item #3 above.	Same supplier as in item #3 above.
5.	Liquid pure silver solder - Dynaloy #340 solder.	Dynaloy, Inc. 7 Great Meadow Lane Hanover, New Jersey
6.	Solder - Alloy #SN-60 Ersin Multicore	Brookstone Co. Peterborough, New Hampshire
7.	Lacing Cord - Alpha wire #LC-132 white.	Bond Radio Electronics, Inc. 439 West Main St. Waterbury, Conn.

Material		Supplier
8.	1/2 inch fiberglass electrical tape - Scotch Brand.	Minnesota Mining & Mfg. St. Paul, Minn.
9.	Part #M211L 040521 KLIXON Thermostats	Texas Instruments, Inc. 34 Forest St. Attleboro, Mass. 02703
10.	Nylon Glove Liners 40 denier nylon - made to four size specifications: • Men's small, medium, large, and extra-large. Patterns and fit developed in conjunction with Clothing and Organic Materials Division, U. S. Army Natick Laboratories Natick, Mass. Patterns on file at Natick Labs.	Grandoe Glove Corp. 70-82 Bleeker St. Gloversville, N. Y. 12078
11.	Deerskin outer leather shells: (leather certification on file at Natick Labs) to meet specification KK-L168C - chrome tanned. Palm side inseam sewn with nylon thread selected from V-T-295C. Back of thumb, hand and fingers contain a 2 oz. polyester batting, covered with an aluminum coated fabric - reflective side toward the hand. (Batting and reflective fabric supplied by the Government). Four sizes developed: Men's small, medium, large and extra-large. Patterns on file at Natick Labs.	Grandoe Glove Corp. 70-82 Bleeker St. Gloversville, N. Y. 12078
12.	Snap type connective (power source) devices - socket #3021 stud #3031, eyelet #3041, front #1-2016.	Rau Fastener 102 Westfield St. Providence, R. I. 02907

Material	Supplier
13. Fabric reinforcement for snap fasteners #10 Army Duck laminated to #2.20 Cotton Drill.	UNIROYAL, Inc. Footwear Plant Naugatuck, Conn. 06770

PHASE I

MANUFACTURING PROCESS DETAILS

GENERAL DESCRIPTION OF PROCESS

The basic process for manufacturing the glove heater is as follows:

1. Encapsulate resistance wire by using a mold containing 66 interconnected longitudinal grooves, with pins at either end of grooves. Wire is threaded up first groove, around pin, down second groove, etc. Encapsulation is achieved by first flowing urethane in the bottom of the grooves, placing the wire, flowing urethane over wire to top of groove. The mold contains lateral grooves on 0.375 inch spacings connecting the longitudinal grooves. Alternate spacing of these lateral grooves between the longitudinal wire grooves 0.186 inches apart, allows the finished heater to be stretched and annealed with heat, forming the originally longitudinal encapsulated wires into diamond shaped patterns.

2. The stretched out heater folds laterally on itself. The fold becomes the small finger side of the hand. Slits are made a suitable distance down from the top to form the back and front of the fingers, subsequently held together by lacing. The portion used to form the thumb is folded on itself to form the thumb area.

3. The laced heater is stretched over a porcelain hand form on which the nylon liner has been fitted. The heater is cemented to the nylon liner at strategic points.

4. Thermostat is attached and final electrical connections made.

5. The formed heater is inserted in the leather glove, (+) and (-) leads soldered to the snap fasteners in the underside of the glove, and the nylon glove liner and heater finally hemmed to the leather at the cuff area.

DETAILS OF WIRING AND MOLDING OPERATION

The basic principle of forming the thermoplastic urethane sheet into the grooves of the mold is:

- lay the sheets of plastic on the mold
- cover with a resilient silicone rubber pad and top plate
- place in platen press
- heat, using a chosen time temperature cycle to melt the plastic so that the silicone forces the softened plastic into the grooves, and
- cool while under pressure.

A platen press using electric or steam for heating, and having water cooling passages in order to alternately heat and cool the platens, normally would be used. Since a press fitted with water cooling capabilities was not available at the location where the work was performed, the mold itself was designed for water cooling. The press used was a 2 "deck" press (4 platens). To substitute for a normal cooling cycle, the mold was removed from the top "deck", which was heated, and placed in the bottom "deck" which was heated. Water was run through the mold proper to speed the cooling cycle while the mold was in the bottom "deck". Using this equipment in this manner, the details are as follows:

1. Cut 2 sheets of 0.005 inch thick urethane, to fit the outside dimensions of the mold, and place on top of the mold. Place a silicone pad 1/16 inch thick over the urethane with a 3/8 inch aluminum cover plate on top.

2. Place above "sandwich" in the platen press with platen temperatures 270°F, 7 tons PSI pressure, for 1.5 minutes. Open platens and move mold to bottom "deck" of press, connecting water supply and discharge hoses to mold. Close press and raise pressure to 12 tons PSI. Open press after 2 minutes, turn water on and cool mold to 140°F.

3. Remove the cover and silicone rubber pad.

4. Prepare 2 30 inch lengths of teflon insulated lead-in wires.

by baring the insulation with wire strippers 3/16 inch in 8 places spaced 2 inches apart, starting fron one end. Bend the wire 180° at each place where insulation is removed.

5. Tie (using clove hitch knot) the end of the resistance wire to the first bared area nearest the long end of one lead-in wire. Press doubled lead-in wire in slot provided in mold and push up to the pin. Thread wire up and down grooves, around pins at top and bottom of mold. The size of the pins (0.031 inch) located midway between the grooves, was designed to center the wire (0.014 inch) in each groove (0.032 inch). After threading up and down 3 times, the 6th groove will lead to 1 inch from the bottom of the mold, where the start of the 2nd lead-in wire is to be connected. The resistance wire is looped around the 1st bared area of the 2nd lead-in wire and pulled toward the top of the mold as the lead-in wire is pushed toward the pin in the groove provided for it. The mold is continued to be wired in this manner taking care to use alternate lead-in wires to connect to the resistance wire each time the wire in the groove goes 1 inch from the bottom of the mold. With one lead-in wire eventually becoming (+) polarity and the 2nd (-) polarity, the heater is divided into 15 separate circuits with the lead-in wires providing a parallel circuit to feed the resistance circuits. At the finish of the wiring, the end of the resistance wire is double wound around the lead-in wire to prevent slippage.

6. Apply the pure silver (suspended in a solvent and melamine plastic) with a toothpick to each area where the resistance wire passes around the lead-in wire. Air dry the silver suspension 1/2 hour to permit solvent evaporation. The silver becomes embedded in the core of the resistance wire and completely encapsulates the contact points between the lead-in and resistance wire.

7. Cut 2 sheets of the 0.005 inch thick urethane to fit the outside mold dimensions and place on top of the wired mold. Cut a 0.006 inch copper shim stock sheet to fit the outside dimensions of the mold and spray 1 side with silicone, and place siliconed side on top of the urethane sheets. Place the silicone rubber pad over the copper, with the aluminum cover plate on top.

8. Place this "sandwich" in the top "deck" of the press with the platens at 300°F temperature, and hold for 12 minutes at 10 tons PSI pressure and 3 minutes at 35 tons PSI pressure. Open press and move the mold to the bottom "deck" and allow to cool for 3 minutes at 35 tons PSI. Turn water on for 1 minute and open press and remove mold. The purpose of this

cycle is to soften the urethane to just below the melting point, and force it into the grooves by adding increased pressure. The copper indents into the grooves, cutting the material cleanly along the top edge of each groove.

9. Remove the cover, silicone pad and shim stock. The heater is now ready to be removed from the mold. Since the pins in the mold are inserted at a 60° angle to prevent the resistance wire from slipping off the pins during the wiring operation, the heater is locked in the mold. To facilitate removal, the mold was designed with a section of the bottom portion held in place with flat head socket cap screws. By removing these cap screws with an Allen wrench, this section can be lifted up, releasing the tension of the heater around the pins in the mold, and the heater can be stripped from the mold. Refer to pictures #1 and #2 in appendix.

10. After stripping, separate the lead-in wires so that the 16 exposed connections coated with silver do not contact one another. Check the circuit with an ohmmeter. A reading of 9.6 (± 0.2) indicates that the circuit is complete with no breaks in the resistance wire, and good low resistance connections from the lead-in wires to the resistance wire.

11. In order to stretch out the heater, a stretch-annealing board was made. Refer to sketch #2 in appendix. Pins were placed in the board to stretch the heater from the original dimensions of 16 inches long, 3 inches wide, to 10-3/4 inches high, 10 inches wide. The lateral openings formed at the edges of the heater are used to place over the pins. Refer to picture #3 in appendix.

12. A heat source of 180°F for 1 hour is required to anneal the heater in the stretched position. For convenience, the heat source used is electrical. Connect the lead-in wires to the direct circuit voltage supply and pass 24 volts through the resistance circuits for 1 hour. This method also serves as a quality check, since the amperage is monitored (2.5 amp ± 0.2) assuring that all 15 circuits are functioning properly. After annealing, cool the heater for 10 minutes before removing from the stretch board.

13. The conductive silver previously placed on each lead-in wire to resistance wire becomes hard in the final molding operation. However, it is also brittle. To strengthen the connection, solder is applied to the silver. Using a fine tipped soldering iron, apply heat to the silver, and run the solder into the silver, forming a strong, firm connection.

14. Now insulate the connections by coating with a urethane cement. Prepare the cement by dissolving 2 inch square cuttings from the 0.005 inch urethane sheet in solvent (Tetra Hydra Furan) to a 20% to 25% total solids content. Use an eye-dropper to apply the cement around the connection. Allow to dry for 30 minutes. The solvent evaporates leaving the connection encapsulated in a urethane film. At this point, visually inspect the heater for complete resistance wire encapsulation. Also treat the areas where the wire was threaded around the pins with the cement and allow to dry.

15. For additional strength and protection, wrap the lead-in connections with a 3/4 inch length of 1/2 inch wide fiberglass electrical tape.

16. The final operation in manufacturing the heater is to test the circuits. Attach the leads to an ohmmeter. The resistance should read 9.6 ($\pm$ 0.2) ohms. Physically crumble the heater in the hands while monitoring the ohmmeter. The needle must remain stationary. Any movement indicates a poor lead-in connection or a partially fractured resistance wire caused by faulty mold wiring.

DIFFICULTIES ENCOUNTERED IN MANUFACTURING THE HEATER

1. The hand wiring of the mold requires a high degree of finger dexterity, especially as the resistance wire is passed around the lead-in wire and pulled in place. Since the resistance wire is spiral wound, any relaxed tension during the wiring operation causes the wire to "kink". A simple spool let-off device with a spring tension arrangement to control the tension as the wire was pulled off the spool was eventually employed. Refer to picture #4 in appendix.

2. Extreme care has to be exercised to make certain the resistance wire was centered in each groove before the final molding operation to insure complete encapsulation without fracturing the wire.

3. The conductive silver (in a solvent and melamine plastic suspension) settles rapidly and must be stirred before each use, or the silver content of the liq id as applied will not be sufficient to accept the solder later applied.

FITTING THE HEATER TO THE NYLON GLOVE LINER

1. The heater lattice is cut between the finger areas in order to form the front and back of each finger, as the heater is folded laterally on itself. Refer to picture #5 in appendix. The mold design incorporates extra spacing between the finger areas, so that the connecting links that have to be cut are readily seen. The number of connecting links to be cut down from the top of the heater for the four sizes are as follows:

	Between Fingers	Between Thumb and 1st Finger
Size Small	15 links	11 links
Size Medium	16 links	12 links
Size Large	17 links	13 links
Size Extra Large	17 links	14 links

2. In order to make a right hand glove, the heater is positioned flat on the bench with the thumb area to the left. The heater is folded over on itself from left to right; the thumb area from right to left. A left hand glove is made in the opposite manner.

3. A 30 inch length of the flat lacing cord is threaded in a 3 inch curved upholstery needle and knotted.

   - The end of the lacing is tied to the top diamonds of the small finger, closing the front and back at this point.
   - The front and back matching diamond openings are laced from the inside top of the finger to one diamond below the crotch area; crossing over 1 diamond and lacing up the outside of the 3rd finger, tieing off at the top.
   - The other fingers are laced in the same manner.

In order to control the proper amount of necessary slack in the lacing, a "spacing wire" is employed. This is made from a 17 inch length of 0.10 inch diameter steel drill rod. The rod is bend 180^{o} in the middle to form 2 parallel members 1-1/8 inch apart.

The back and front of each finger consists of vertical

rows of 3 lateral diamond patterns.

- One member of the spacing wire is threaded vertically, from the top down, in and out of the center diamonds. This serves to hold the front and back of the fingers together while lacing.
- The 2nd member of the "spacing wire" becomes parallel to edge of the finger area.
- The lacing is passed around the wire thus controlling the slack needed to complete a round finger.
- After 1 side of a finger is laced, the "spacing wire" is pulled out and re-inserted to lace the opposite side, etc., for each finger. Refer to picture #6 in appendix.

4. The 1st finger (adjoining the thumb) is laced down 23 spaces and tied. The thumb is laced down 17 spaces. The final lacing to close the area in the back of the hand and thumb crotch is performed after the heater is fitted over the nylon liner mounted on the porcelain hand form.

5. The nylon glove liner is donned on the appropriate size porcelain hand form, with sewn seams on inside of glove. A shaped receptacle for the thermostat is made by:

   - Placing the thermostat flat on the bench.
   - Placing a 2 inch circular disc, cut from 0.025 clear urethane film, on top of the thermostat.
   - Heating the circular disc with a heat lamp, until the urethane softens and flows around the thermostat.
   - Allowing to cool.
   - Trimming at the area of the thermostat terminals to expose terminals.

   The thermostat is fastened to the glove liner on the back of the hand 1 inch below the thumb crotch, using the 20% to 25% total solids urethane cement, to cement the shaped receptacle containing the thermostat to the nylon glove. Care must be taken to place the thermostat in the receptacle so that the words "temp. side" are against the nylon liner.

6. The laced glove is fitted over the nylon liner on the porcelain

hand form. The diamond shapes are spaced as evenly as possible on the finger areas.

7. Starting at the bottom, the back of the heater is laced together up to the thumb crotch area, completing the lacing to form the hand configuration.

8. The ends of the heating circuits at the finger and thumb areas (formed where resistance wire is looped around pins in the molding operation) are cemented (using the 20% to 25% urethane cement) to the finger-tips, taking care to have the actual encapsulated heating wire on the extreme tips of the fingers.

9. Since the heater is now stretched to a glove shape, an additional annealing operation is necessary. This is performed by connecting the 2 lead-in wires to the direct current power source, and annealing 1 hour with 24 volts (180°F), and allowing to cool.

10. The heater is tacked to the glove liner with the urethane cement. Using an eye-dropper, drops of cement are applied in the heater diamond areas at:

    - Center diamonds from top to bottom, front and back, of each finger and thumb.
    - Around the hand - 1 inch below the finger crotches.
    - Around the wrist area - 1 inch above the bottom.

    Refer to picture #7 in appendix.

11. One lead-in wire is threaded through the diamond openings, up to one of the exposed thermostat terminals and soldered, taking care not to touch the encapsulated heater wires with the soldering iron. One end of a 7 inch length of Teflon coated lead-in wire is soldered to the other thermostat wire, and the wire threaded to a point in the back of the hand approximately 3 inches from the cuff. The remaining lead-in wire is also threaded to the back of the hand to the same general area.

12. The soldered connections to the thermostat are coated with the urethane cement and allowed to dry. A 3/4 inch by 2 inch piece of the 0.005 urethane film is cemented over heater and thermostat (including the wire connections), to further hold the thermostat assembly firmly in place.

13. The glove liner and heater assembly is removed from the porcelain

hand form.

14. At this point, the circuit is finally checked electrically before fitting the heater in the leather glove. Since the thermostats are now connected in the circuit, it is necessary to cool the assembly in a cold box to approximately 60°F to assure that the thermostat contacts are in a closed position. After cooling, 12 volts direct current is connected to the lead-in wires, monitoring the amperage. Specifications call for 15 watts (± 0.3). Therefore, the amperage drawn at 12 volts must be 1.25 (± 0.25). The actual amperage of each glove is noted for final test result reporting for the wattage rating of each glove. The current is allowed to remain on until the thermostat reaches 72°F and opens, assuring that the thermostat is functioning properly.

DIFFICULTIES ENCOUNTERED IN THE HAND LACING OPERATION

1. Trial and error operator training was required to lace the heater to fit the 4 required sizes. The lacing was eventually laced tight around the "spacing wire" for the small size, and slightly looser for each larger size. On size extra large, the final lacing stretched the glove to the extent that in some cases the connecting links between the diamonds parted during the final annealing operations. This could be overcome in the future by altering the mold design to increase the thickness of the connecting links from 0.032 inches deep by 0.032 inches wide, to 0.032 inches deep by 0.060 inches wide. The links would then be sufficiently strong to stand the stretching and annealing without breaking.

FITTING THE HEATER ASSEMBLY IN THE LEATHER GLOVE

1. The leather glove shell as manufactured by Grandoe Glove Corp. (to specifications listed under Materials and Suppliers section) is complete with the snap fasteners used for the final electrical connections. The snap fasteners are inserted as follows:

   - A 2-1/4 inch wide by 1-1/4 inch high reinforcement is cut from the laminated Army Duck.
   - Two holes of 1/16 inch diameter, spaced on 1 inch centers are punched in the reinforcement. (Centered top to bottom, side to side)
   - The reinforcement is sewn on the inside of the center back of the glove, with the bottom edge of the reinforcement 1-1/2 inches from the edge of the cuff (before hemming).
   - The 1/16 inch diameter holes are also punched through the glove (and the reflective backing and batting previously sewn in), using the holes in the reinforcement for indexing.
   - The snap fasteners are pressed in, using a press equipped with the required dies to properly set the fasteners.
   - The socket #3021 is located on the outside of the glove, with the front #1-2016 on the inside, in the hole toward the thumb side of the glove. The eyelet #3041 is located on the inside, with stud #3031 on the outside, in the remaining hole. (Picture #8)

2. The heater assembly is donned on a human hand and the leather shell pulled over. The friction of the polyester batting in the glove shell against the lattice heater makes it difficult to work the fingers of the heater assembly completely into the fingers, of the leather shell. A 1/2 inch diameter wooden dowel rod, rounded at the end, is used to push the fingers of the heater all the way in the fingers of the glove shell.

3. Because the heater is made up of a diamond shaped lattice configuration, there is some tendency for a "telescoping" effect, when donning and doffing the glove. As the glove

fingers are stretched during donning and doffing, they become tighter. It was found that donning the entire assembly on the porcelain hand form, and heat treating in an oven at 160° for 2 hours, the effect was minimized because the leather glove and heater are heat set to the same configuration. Repeated donning and doffing (100 cycles) makes no change in feel and comfort on the hand.

4. The lead-in wires (1 from the thermostat and 1 direct from the glove circuit) are soldered to the snap fasteners.

   - The cuff of glove is folded back to expose back side of fasteners.
   - Using the soldering iron and solder, fasteners and the bared wire ends are tinned.
   - The wire ends are soldered to fasteners.
   - The soldered connections are insulated by coating with cement, letting dry for 30 minutes.

5. Labels for each glove are prepared using a cotton, 80 inch square nainsook fabric, and typing the required information on a 3/4 inch by 1-1/2 inch size. The information required is:

   - Contract number
   - Size
   - Type (designated type A for Phase I construction)
   - Quality control number

6. The glove is machine hemmed at the cuff area, catching the nylon liner during the hemming operation. The label is also hemmed to the inside of the glove on the back side. (Ref. to picture #9 in appendix)

7. The pairs of gloves are packaged in a suitable size polyethylene bag and boxed in a 5 inch by 12 inch by 3 inch full telescope chipboard box. A label is placed on each box containing contract number, size and type.

DIFFICULTIES ENCOUNTERED IN FINAL ASSEMBLY

1. Extreme care had to be taken to push the lead-in wires in the glove during the final machine hemming operation. The mold was designed with the resistance wire extending down 1 inch from the bottom edge of the heater in each area where the lead-in connections had to be made. This was done so that in case the lead-in wires could not be connected during the resistance wiring operation, sufficient length of resistance wire would be available to remove the insulation and make the necessary connections as a post operation. Since making the lead-in connections during the wiring of the mold proved practical, the additional 1 inch length is not required and the mold design can be altered. This would eliminate 16 ends, where the lead-in wires are connected, protruding down 1 inch from the bottom edge of the heater. The hemming operation would thus be simplified.

GLOVE HEATER SPECIFICATIONS

Wattage required per circuit	-	1
Wattage required per glove	-	15
Resistance per circuit	-	144 ohms
Resistance per glove	-	9.6 ohms
Length of 1 circuit	-	5.65 feet
Circuits per finger	-	3
Circuits per glove	-	15
Total wire in glove	-	85 feet

FINAL TEST DATA

Size Small

Pr.#	Number of Glove	Amps @ 12 V	Watts	Pr.#	Number of Glove	Amps @ 12 V	Watts
1.	51	1.25	15.0	9.	48	1.33	15.96
	69	1.30	15.6		49	1.30	15.6
2.	50	1.26	15.12	10.	47	1.30	15.6
	68	1.29	15.48		55	1.35	16.2
3.	66	1.38	16.56	11.	44	1.32	15.84
	70	1.38	16.56		45	1.36	16.32
4.	63	1.35	16.2	12.	42	1.33	15.96
	64	1.35	16.2		43	1.29	15.48
5.	62	1.35	16.2	13.	40	1.36	16.32
	65	1.22	14.64		41	1.30	15.6
6.	60	1.32	15.84	14.	38	1.34	16.08
	61	1.35	16.2		39	1.30	15.6
7.	56	1.35	16.2	15.	36	1.30	15.6
	59	1.34	16.08		37	1.30	15.6
8.	52	1.31	15.72	16.	34	1.31	15.72
	54	1.33	15.96		35	1.31	15.72

FINAL TEST DATA

Size Medium

Pr.#	Number of Glove	Amps @ 12 V	Watts	Pr.#	Number of Glove	Amps @ 12 V	Watts
1.	5	1.22	14.64	9.	17	1.35	16.2
	6	1.34	16.08		23	1.29	15.48
2.	4	1.30	15.6	10.	22	1.34	16.08
	12	1.33	15.96		24	1.26	15.12
3.	7	1.34	16.08	11.	25	1.31	15.72
	8	1.33	15.96		26	1.29	15.48
4.	19	1.32	15.84	12.	27	1.25	15.0
	11	1.33	15.96		28	1.25	15.0
5.	9	1.27	15.24	13.	29	1.26	15.12
	10	1.37	16.44		20	1.33	15.96
6.	13	1.21	14.52	14.	30	1.21	14.52
	14	1.25	15.0		31	1.20	14.4
7.	15	1.35	16.2	15.	32	1.29	15.48
	16	1.26	15.12		33	1.33	15.96
8.	18	1.30	15.6				
	21	1.34	16.08				

FINAL TEST DATA

Size Large

Pr.#	Number of Glove	Amps @ 12 V	Watts	Pr.#	Number of Glove	Amps @ 12 V	Watts
1.	71	1.36	16.32	9.	88	1.34	16.08
	72	1.36	16.32		84	1.34	16.08
2.	73	1.35	16.2	10.	89	1.32	15.84
	74	1.30	15.6		91	1.33	15.96
3.	75	1.34	16.08	11.	90	1.34	16.08
	76	1.36	16.32		94	1.35	16.2
4.	77	1.35	16.2	12.	92	1.34	16.08
	78	1.26	15.12		93	1.35	16.2
5.	79	1.31	15.72	13.	95	1.34	16.08
	80	1.35	16.2		96	1.36	16.32
6.	81	1.36	16.32	14.	97	1.26	15.12
	82	1.26	15.12		98	1.26	15.12
7.	83	1.27	15.24	15.	99	1.31	15.72
	87	1.32	15.84		102	1.34	16.08
8.	85	1.36	16.32	16.	100	1.30	15.6
	86	1.36	16.32		101	1.30	15.6

FINAL TEST DATA

Size Extra Large

Pr.#	Number of Glove	Amps @ 12 V	Watts	Pr.#	Number of Glove	Amps @ 12 V	Watts
1.	103	1.34	16.08	9.	119	1.27	15.24
	104	1.34	16.08		120	1.34	16.08
2.	105	1.35	16.2	10.	121	1.25	15.0
	106	1.35	16.2		122	1.34	16.08
3.	107	1.30	15.6	11.	123	1.31	15.72
	108	1.26	15.12		124	1.26	15.12
4.	109	1.34	16.08	12.	125	1.35	16.2
	110	1.28	15.36		126	1.35	16.2
5.	111	1.27	15.24	13.	127	1.26	15.12
	112	1.33	15.96		128	1.26	15.12
6.	113	1.24	14.88	14.	129	1.34	16.08
	114	1.32	15.84		130	1.35	16.2
7.	115	1.34	16.08	15.	131	1.35	16.2
	116	1.25	15.0		132	1.35	16.2
8.	117	1.35	16.2	16.	133	1.34	16.08
	118	1.35	16.2		134	1.34	16.08

OBSERVATIONS AND RECOMMENDATIONS - PHASE I

1. Gloves produced in this manner on a production basis would still be quite costly from a labor standpoint. For the glove heater, ready to insert in an outer shell, it is estimated that it would require three trained operators to produce 3 pairs per 8 hour day. The hand lacing and fitting is the most laborious of the total operations.

2. The reflective backing on the cotton duck material used on the back of the leather glove, as supplied by the U. S. Army, reduces the dexterity of the finger movement. While this was the only readily available material at the time, a lighter, reflective material with more stretch should be sought for the purpose.

3. While the molding and lacing method to produce a heating circuit for gloves might be superseded by a less costly method, it should be kept in mind for other applications. At the request of Natick Laboratories, the same expanded heating element was cemented around a sock lining and successfully incorporated in a cast urethane boot. With proper mold design, the cementing of the heater to the foot area, would be a relatively fast operation, particularly adaptable to the cast urethane insulated boot under development at this time.

PHASE II - DEVELOPMENT OF AN ALTERNATE METHOD

It was contemplated early in the development efforts that the most commercial method would be to machine knit the resistance wire directly in the glove. Further development was therefore directed toward this end. A program was designed to:

- Choose an insulating material.
- Determine if the 0.014 inch gauge tinsel wire could be extrusion coated.
- Explore the use of the coated resistance wire in a knitting operation.
- If successful, design a circuit to provide heat to the required areas, with a 15-watt rating at 12 volts direct current.
- Program the circuit for the machine knitting and make production trials.
- Produce the required gloves by a knitting method.

Insulating The Resistance Wire

1. Several insulating materials were considered. Many, such as polyvinyl chloride, were discarded because of poor flexing characteristics at extremely low temperatures. Materials considered that are commonly extruded and will not flex-crack at -65°F were:

- Teflon
- TPR (Trade name for UniRoyal, Inc. thermoplastic).
- Royalar (Trade name for UniRoyal, Inc. thermoplastic urethane).

2. Other factors for consideration were the flexibility of the material (Shore A hardness), and the solubility of the material in a solvent. If knitting a circuit proved practical, connections would eventually have to be made to the insulated resistance wire. It was assumed that extruding the insulation material around the wire would imbed this material in the polyester core, making stripping with a wire stripper impossible.

3. Since Royalar (thermoplastic urethane) is readily soluble in Tetra Hydra Furan, coupled with the fact that the molded method incorporated a thermoplastic urethane, this basic material was chosen.

4. The Research and Development section of UniRoyal, Inc. Chemical Division involved with urethane development was consulted. A material was developed with a Shore A hardness of 70, lubricated with a proprietary lubricant to aid in extruding through a fine diameter die. At their suggestion Henry Meyer Co., Hamden, Conn., was chosen for the experimental work. Successful trials were made on a cross head extruder at this plant. The final gauge of the extruded resistance wire was 0.026 ($\pm$ 0.005) inches. The UniRoyal material designation is Royalar E-80.

Knitting Trials

At the recommendation of Mr. Herman Madnick, U. S. Army Natick Labs, Zwicker Knitting Mills, Appleton, Wisconsin was chosen.

Knitting trials were made at their plant, using a machine of their design and manufacture that program knits a complete glove, with the exception of closing the finger-tips. The resistance wire was substituted for the dacron yarn normally used to determine how the wire acted in the machine. After much adjusting of tensions, and other machine operating parameters, lubricating the resistance wire, etc., a palm section of a glove was successfully knitted. A finger section was also knitted with satisfactory results. Electrical continuity from start to finish of each knitted section was checked and found to be positive.

1. It was decided that the knitting was practical. The resistance wire would have to run across the glove and fingers, since this was the manner in which the glove was knitted.

2. For circuit design and length of wire to be used in each circuit, it was necessary to determine the inches of wire that was knit in each row across the palm area. This was accomplished by reading the ohms resistance from beginning to end of the knitted sections. With a known resistance of 25.5 ohms per foot, the length of the wire was calculated. The total length used was divided by the number of rows knit to determine the length per row, both in the palm area and the finger area.

Circuit Design

1. The original design contained 15 circuits. The knitting machine capabilities made a 15 circuit design impossible. The machine could feed a maximum of 6 ends. Since 1 end of yarn would be required, 5 ends of wire could be used. By keeping to the original 85 feet of wire per glove, it was decided to program the knitting machine to knit 5 circuits, each with 17 feet of resistance wire. Each circuit would be divided in two with appropriate lead-in connections. The program called

for knitting 5 wires, using 8.5 feet to complete a circuit from the bottom of the wrist to the top of the thumb, and 8.5 feet for the balance of the palm area and the 4 fingers.

2. Since the total of 85 feet of resistance wire would be divided into 10 circuits of 8.5 feet each, rather than 15 circuits of 5.65 feet each, it became necessary to use a wire with less resistance per foot. Using Ohm's law, this was calculated to be 11.3 ohms per foot, resulting in the 9.6 ohms resistance per glove.

$$11.3 \text{ ohms} \times 8.5 \text{ feet per circuit} = 96 \text{ ohms/circuit}$$

$$96 \text{ ohms} \div 10 \text{ circuits} = 9.6 \text{ ohms per glove}$$

Due to certain parameters of the tinsel wire manufacturing process, wire with a resistance of 12 ohms per foot was procured.

3. The 12 ohms/foot resistance wire was urethane coated by extrusion and wound on 5 spools containing 3,000 feet of wire each. During the rewinding operation, a water emulsion silicone was applied to the insulation by running the wire through a sponge saturated with the silicone solution.

Knitting Production Trials of 10 Circuit Glove

1. To knit a complete glove, the knitting machine starts from the bottom and knits:

- Cuff
- Palm to base of thumb
- Thumb
- Upper palm
- Fifth finger
- Fourth finger
- Third finger
- First finger

After completing a finger, the knitting yarn (together with wire in this case) drops down, and picks up stitch in the upper palm area and knits the next finger, etc.

2. The 5 wire program was completed and punched in tapes and

trials made. The trials were unsuccessful due to the manner in which the glove had to be knit.

In order to sequence knit spacing rows of yarn, wire #1, more spacing rows of yarn, wire #2, etc., until the 5 wires were knit. the first repeat of 5 wires had to be held in the "die sinkers" in the knitting machine, before the repeat of wire #1 could start again. The repeated action of the knitting crushed the first wire, breaking the circuit.

The original knitting trials knitted only 1 wire, which dropped out of the "die sinkers" immediately after being knit. A short program was designed to repeat this trial, which, when run, substantiated the fact that if the resistance wire was released as it was knit, the wire would not crush.

3. To be successful, it was apparent that a heating circuit would have to be designed around the knitting machine capabilities. Subsequent studies revealed that an ideal knitting program would be to use 3 feeds of wire alternating in between 3 feeds of yarn. By separating the 3 repeats of wire in 2 places, 9 circuits could be incorporated. Therefore, a program to knit a glove in this manner was designed. Since 9 circuits would now be employed rather than 10, the resistance of each circuit would have to be reduced. This was accomplished by shortening the length of wire from 8.5 feet to 7.2 feet for each circuit:

$$7.2 \text{ feet} \times 12 \text{ ohms/ft.} = 86.4 \text{ ohms per circuit}$$

$$86.4 \div 9 = 9.6 \text{ ohms/glove}$$

Design work indicated that basically equal length circuits could be made by:

- Having first 3 circuits start at cuff area and finish at end of thumb.
- Next 3 circuits to include upper palm area and fifth finger.
- Last 3 circuits for remaining three fingers.

4. Because the wire drops down after knitting the thumb and each finger, it would be possible to bare the insulation at these points and connect appropriate (+) or (-) polarity lead-in wires to these points. Refer to sketch #3 for wire program schematic and diagram of planned lead-in wire connections.

5. It was also possible to program the spacing of the wire to provide increased watt density in the areas where more heat is desired, particularly in the finger-tip areas.

Production Knitting of Gloves

1. The 9 circuit program was successfully run on the knitting machine after trial and error adjustments. In order to avoid the possibility of wire breakage, the tensions were set loose. However, if loops slipped out of the sinkers during knitting, needle breakage or jamming would occur. Tight tensions eliminated this, but caused a fracturing of the wound resistance wire in the fifth finger area, with too high a frequency to be practical. Experimentation with tensions, die sinker settings to control stitch length, machine speeds, etc., eventually led to a good repetitive performance. Fifty pairs of gloves were produced at the approximate rate of 1 glove every 10 minutes, with only 2 failures. The insulation of the 3 wires was bared at start and finish by soaking the ends of the wires in Tetra Hydra Furan for 1 minute and stripping with the fingernails. Continuity was checked with an ohmmeter.

2. The original program was designed to knit a glove for size small and medium. A second program was made, adding rows of yarn in the palm, thumb, and each finger area to produce a glove for size large and extra large.

3. The knitting machine and programming methods are proprietary to the Zwicker Knitting Mills. An agreement was made to keep the programs used permanently on file at their plant.

4. After knitting, the finger-tips were closed by hand knitting. The resistance wires were drawn close to the end of the finger-tips. Refer to pictures #10, #11 and #12 in appendix showing knitted glove before closing fingers, glove after closing fingers, and a glove turned inside out illustrating resistance wire coverage.

5. To complete the 12 pairs of gloves (4 small, 4 medium, 4 large and 4 extra large) it was necessary to:

   - Connect lead-in wires as planned (Refer to sketch #3).
   - Mount thermostat on nylon glove liner.
   - Insert nylon glove liner into the knitted glove.
   - Connect thermostat in the circuit.
   - Sew knit glove to nylon liner.
   - Insert in leather glove shell.
   - Connect lead-in wires to snap fastener.
   - Hem bottom of glove.

6. The original Teflon coated lead-in wires were chosen for the

smooth Teflon insulation in order to consistently fit the grooves provided in the mold. Wire bends remained in place during the wiring operation. Once completed, the lead-in wires would not be repeatedly flexed. However, on the knit version, the lead-in wire would run to the finger areas necessitating good flexing characteristi[illegible] Therefore a TPR (UniRoyal, Inc., thermoplastic rubber) insulated #41/40 tin, hard drawn cadmium bronze wire, meeting MIL spec. #MIL-C-5898 was selected. Source was Meyer Wire Co., Hamden, Conn.

7. While it is possible to solder the lead-in wires to the bared tinsel resistance wire, excessive heat on the tinsel wire might fracture the 0.003 inch wire. Therefore, crimped connections were employed. Crimps designed to handle the total bared wire diameters of 1 lead-in wire together with 3 resistance wires were procured from Amp, Inc., Harrisburg, Pa. (Crimp #41975). The appropriate hand crimping tool was also bought from this source.

8. The lead-in wires are connected in the following manner:

- Bare 1/4 inch of insulation on the resistance wires in between the fourth and fifth finger; between the top of the thumb and palm; the end of the wires at the top of the first finger; and the beginning of the wires at the cuff area, by soaking in Tetra Hydra Furan for 1 minute and stripping with fingernails.
- Crimp 1 end of an 11 inch length of lead-in wire to the 3 bared resistance wires between the fifth and fourth fingers.
- Lace this lead-in wire across the fifth finger, down the side of the glove.
- At the point where the 3 resistance wires begin in the cuff area, bare the lead-in wire and crimp the 3 resistance wires, leaving approximately 4 inches to the end of the lead-in wire.
- Crimp 1 end of a 7 inch length of lead-in wire to the 3 resistance wires at the end of the first finger.
- Lace this lead-in wire down the side of the first finger to the thumb crotch.

- Crimp 1 end of a 4 inch length of lead-in wire to the 3 resistance wires between the top of the thumb and the palm.
- Lace this down the inside of the thumb to the crotch area.

The above connections eventually provide (+) polarity at the start of the glove in the cuff area, and to the resistance wire between the fifth and fourth fingers. A (-) polarity is fed through the thermostat to the resistance wire between the thumb and palm area and to the end of the circuit at the top of the first finger. The circuits from beginning to end are then divided in three by:

- (+) at the beginning in the cuff area, to
- (-) between end of thumb and palm (1 circuit), to
- (+) between fifth and fourth finger (2 circuits), to
- (-) end of circuits at top of first finger (3 circuits).

9. The appropriate size glove liner is donned on the porcelain hand form (seam side out). The thermostat, contained in the heat molded urethane plastic receptacle, is cemented to the glove liner 1 inch below the thumb crotch, in the same manner as previously described for attaching the molded type heater.

10. The proper size knit glove heater is donned over the knit liner. Because the gloves are knitted flat, they can become left or right by turning over.

11. The knit glove is folded back on itself from the cuff area up, to expose the thermostat terminals. The 2 lead-in wires (from the thumb and first finger) are led through the knit glove and soldered to one of the thermostat terminals. A 6 inch length of lead-in wire is soldered to the remaining thermostat terminal. The soldered terminal connections are covered with urethane cement (as previously described) and allowed to dry.

12. The knit glove is pulled down to normal shape and the assembly removed from the porcelain hand form.

13. The crimped connections are coated with urethane cement. The connections at the thumb area, fifth finger area, and at the start of the glove, are wrapped with 1/2 inch of the 1/2 inch wide fiberglass insulating tape.

14. To prevent the nylon liner separating from the knit glove, the knit glove is tacked to the nylon liner by hand sewing. The tacking is started on the outside of the bottom of the thumb and continued up and down the thumb to the crotch area, up and down

each of the fingers. (Refer to picture #13 in appendix showing completed assembly).

15. The knit glove heater is donned on a human hand and the appropriate size leather glove shell (manufactured as previously described) is pulled over the knitted glove.

16. The leather shell is folded back and the lead-in wires (one from the thermostat and one from the cuff area) are soldered to the snap fasteners and insulated (as previously described).

17. The nylon liner is folded back and stitched to the cuff of the knitted glove, leaving 3/8 inch of liner material below the bottom of the cuff of the knitted glove.

18. The bottom of the leather glove is hemmed, catching the 3/8 inch of folded nylon liner material. A typed label is inserted in the back of the hem containing:

    - Contract number.
    - Size
    - Type (knitted version designated as Type B).

19. Before packing in poly bags and chipboard boxes, the circuit of each glove is checked by cooling the glove in a cold box to 60°F to assure the thermostat is closed. The circuit is first checked with an ohmmeter. A reading of 9.6 ohms ($\pm$ 0.2) should be gotten if all connections are correct. The 12 volt direct current power source is then connected, monitoring the amperage drawn (should be 1.25 ($\pm$ 0.2) amps). The current is left on to heat the glove until the thermostat opens, to assure proper functioning of the thermostat.

20. It was noted with great satisfaction that each of the 12 pairs of the gloves produced by the knitted process drew exactly 1.25 amps at 12 volts direct current, giving at rating of exactly 15 watts for every glove.

KNITTED GLOVE HEATER SPECIFICATIONS

Wattage required per circuit	1.67
Wattage required per glove	15
Resistance per circuit	86.4 ohms
Length of one circuit	7.2 feet
Circuits per finger	3
Circuits per glove	9
Total wire in glove	64.8 feet

OBSERVATIONS AND RECOMMENDATIONS KNITTED HEATER - TYPE II

Observations:

1. While equipment was not available to check the caloric heat values on the various parts of the hand, a physical check was made by donning the two types of electrically heated gloves, (after cooling) one on either hand, and attaching to the 12 volt direct current power source.

   It was noted that the knit version heated equally as fast as the molded version. In addition, the heat could be better felt in the extreme finger-tip areas.

2. The knit version had greatly improved finger dexterity and felt more comfortable.

Recommendations:

1. It is recommended that the knit versions be field tested for durability along with the molded types. This will serve to bear out the flex test results that indicate extremely good durability.

2. The knitted version is better suited to mass production, and total costs should approximate 20% of the molded type for the basic glove heater ready to be put into an outer shell.

Acknowledgements:

The author wishes to acknowledge the assistance on each phase of the project provided by Mr. Herman Madnick, Project Officer, Clothing and Personal Life Support Equipment Laboratory.

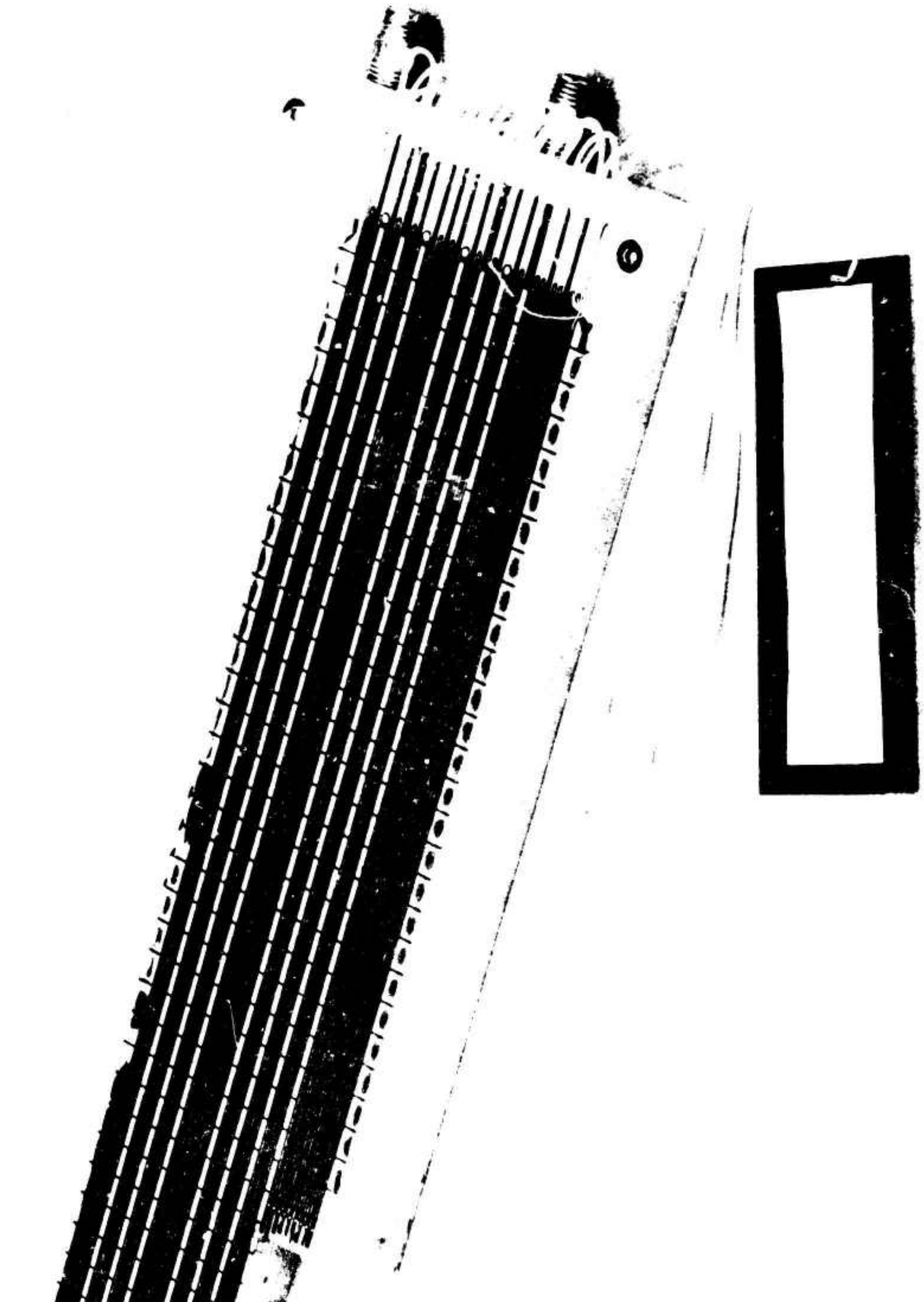
Mr. Mark W. Olson and Mr. W. F. Silva, of UniRoyal, Inc., the original inventors of the lattice glove heater, provided the details of the basic process.

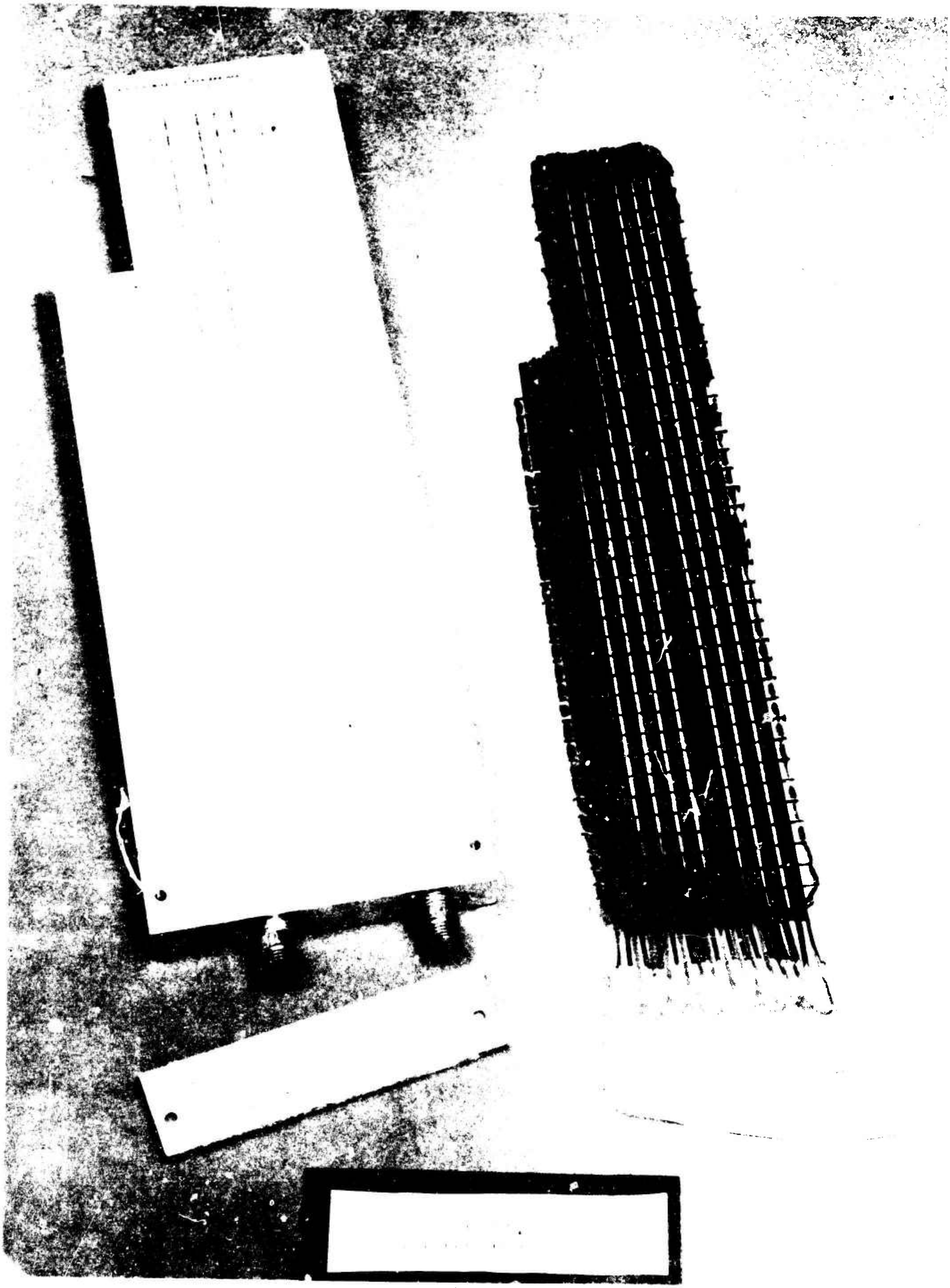
Mr. Bob Drzal, of the Chemical Division, was most helpful in providing a suitable thermoplastic material for extrusion coating the tinsel wire.

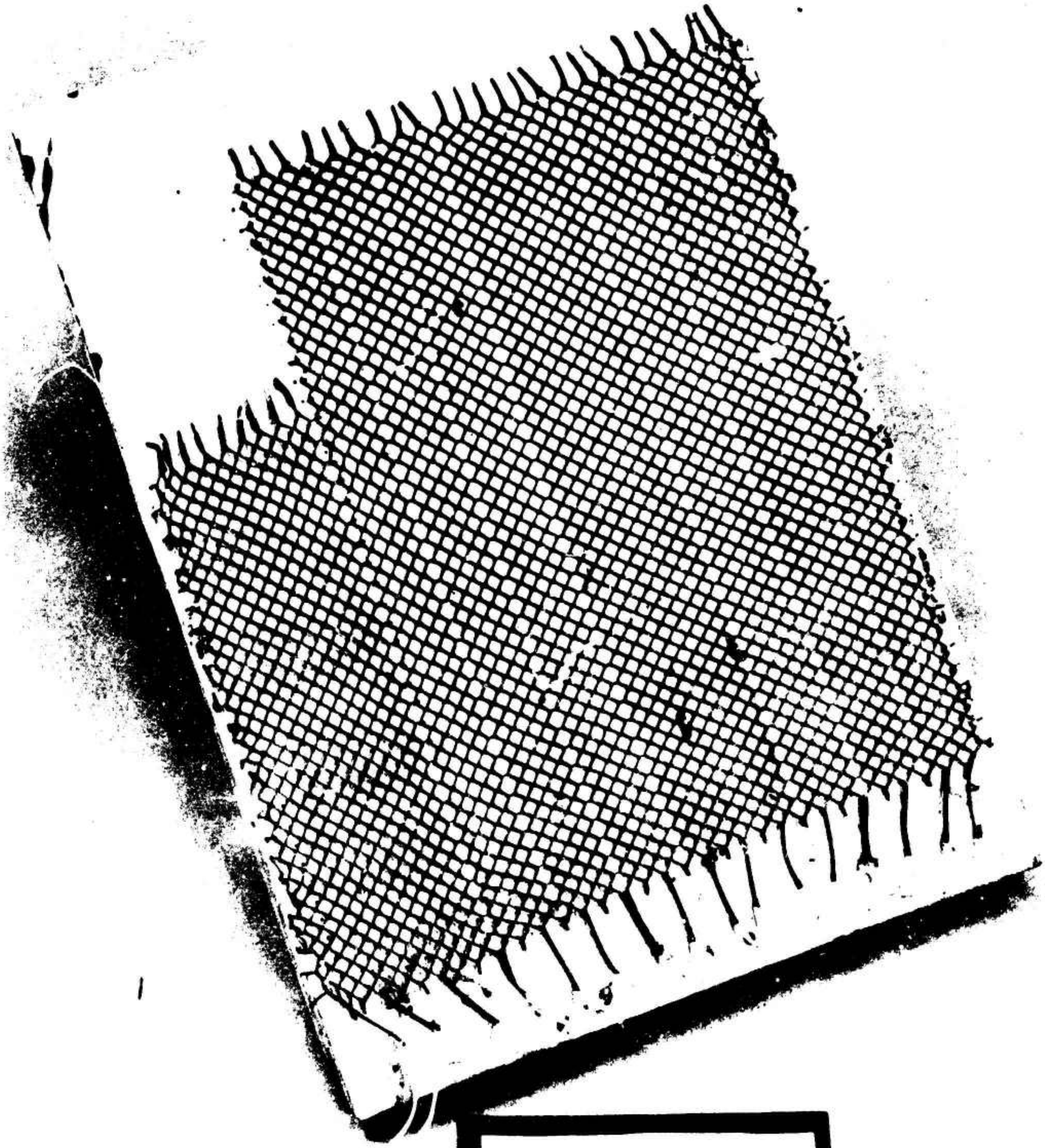
The technical aid and assistance provided by Zwicker Knitting Mills under the direction of Mr. Lloyd Paul and Mr. Ralph Nagreen made the automated knitting possible.

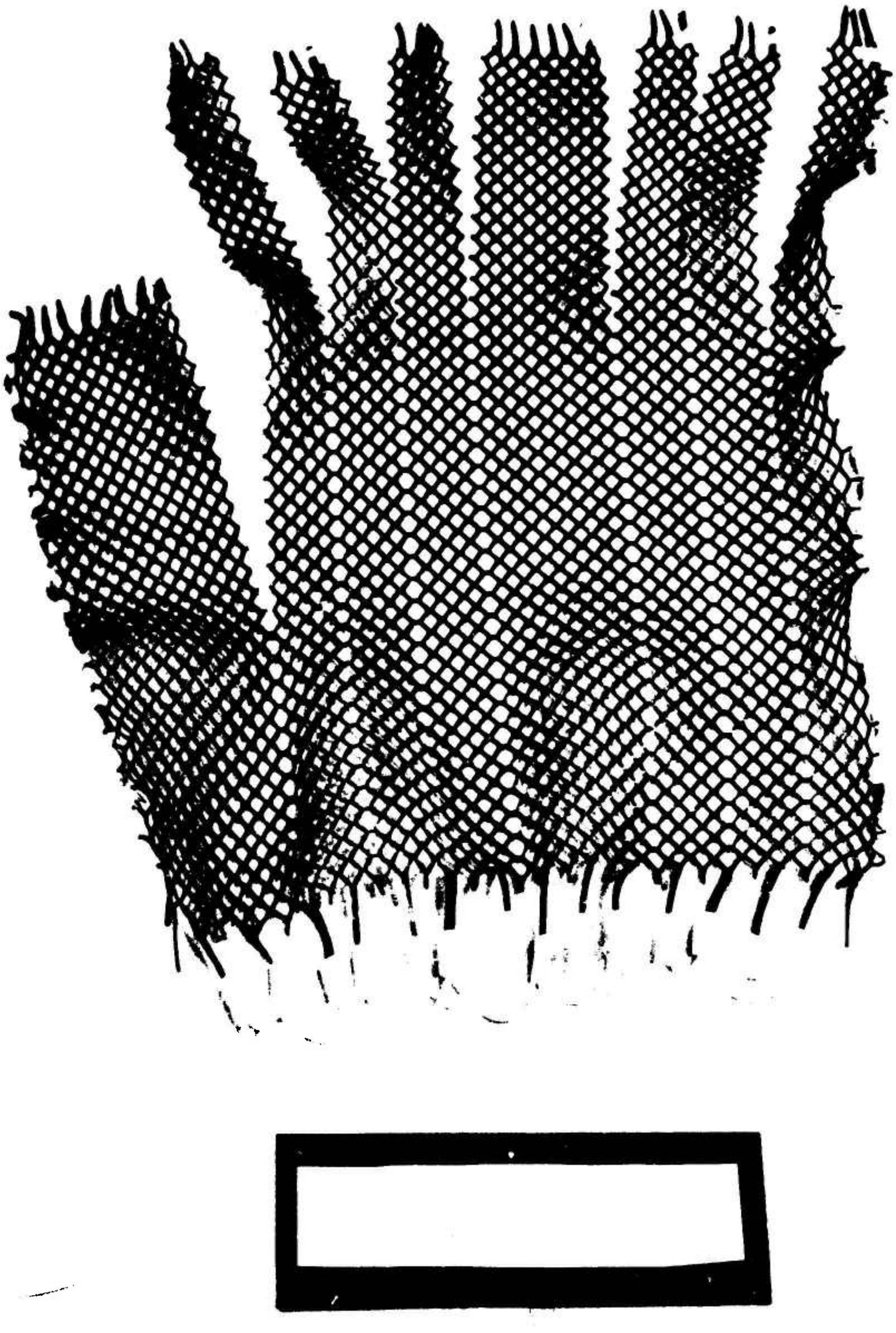
APPENDIX

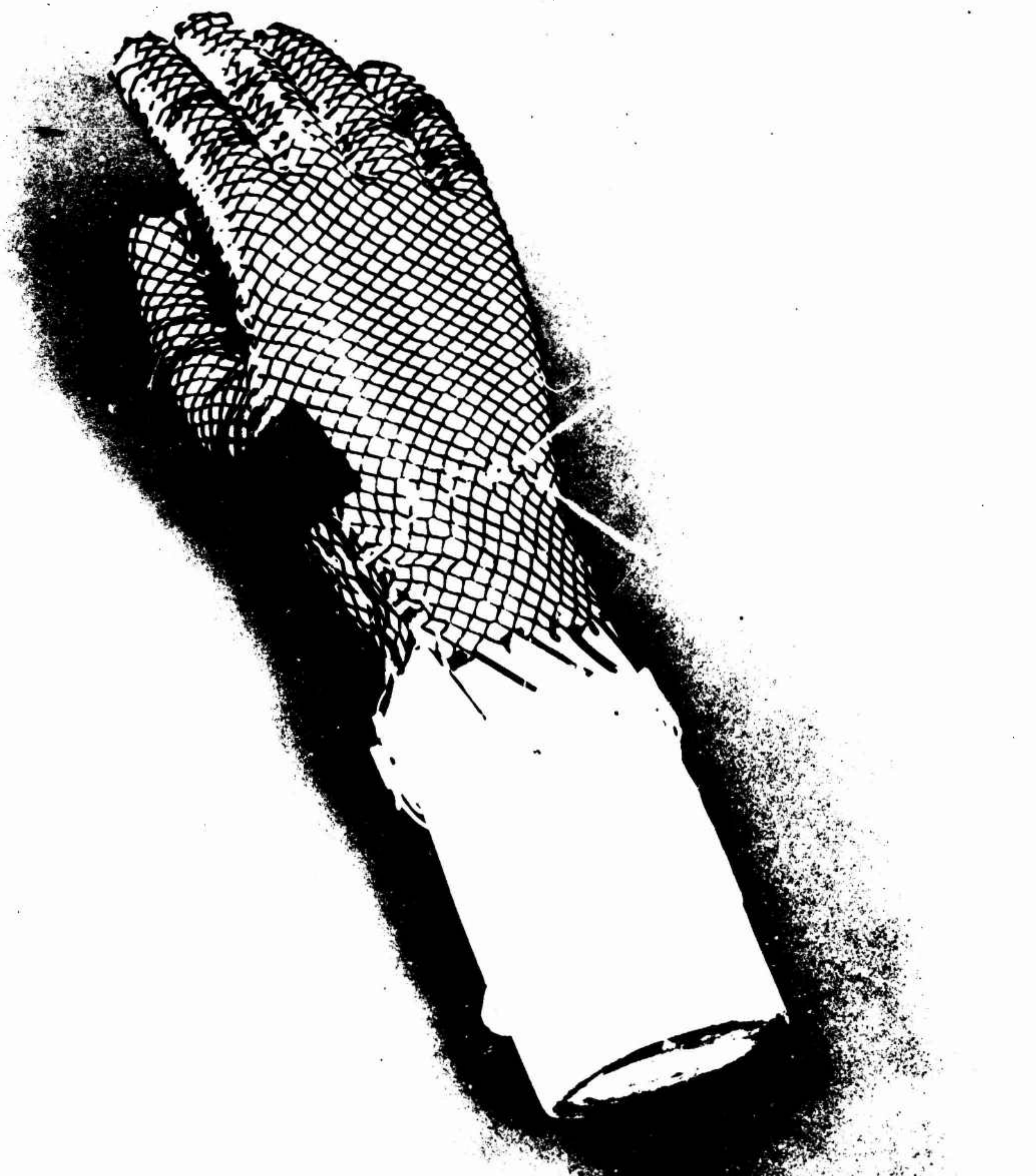
DRAWINGS SKETCHES PHOTOGRAPHS

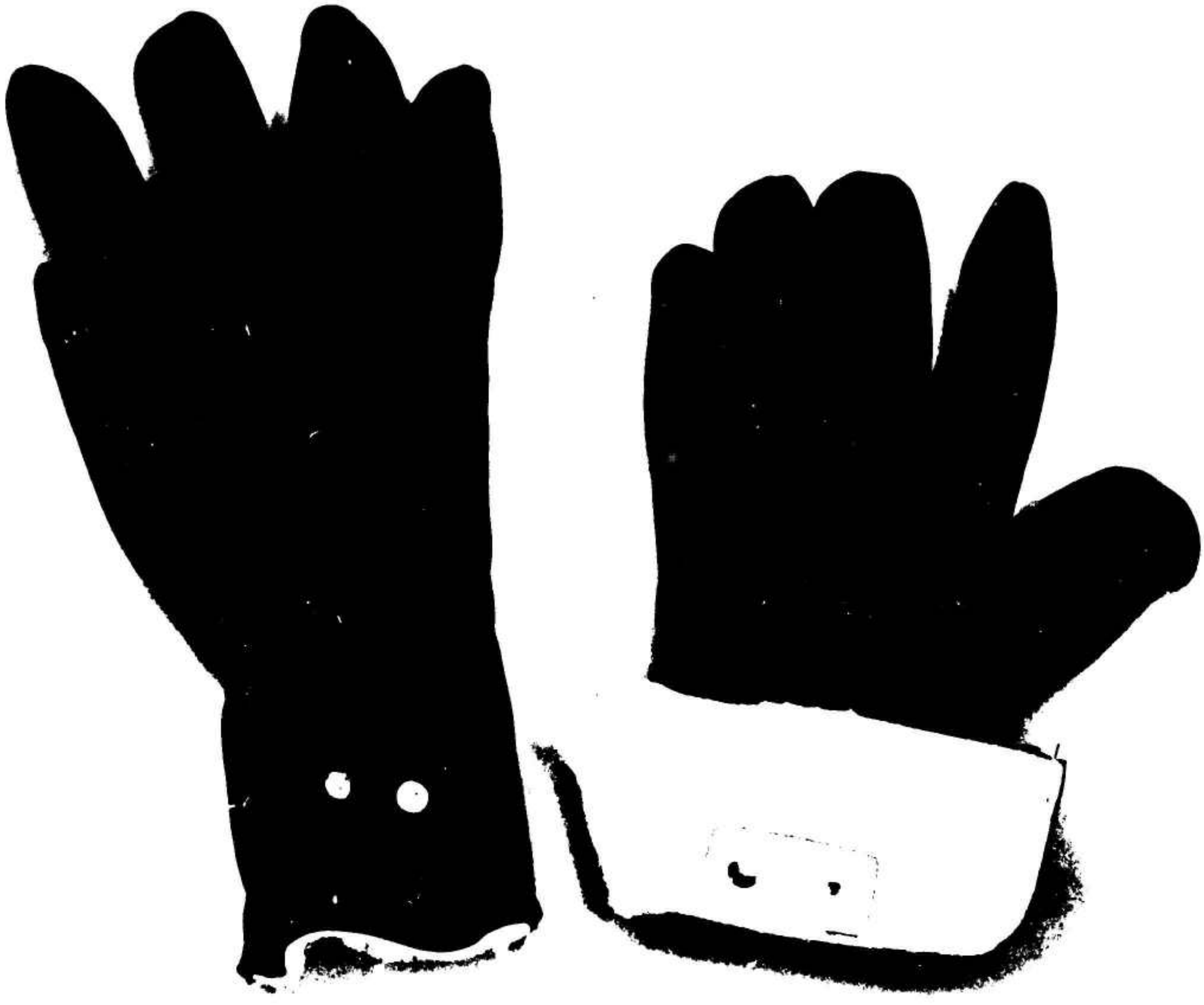


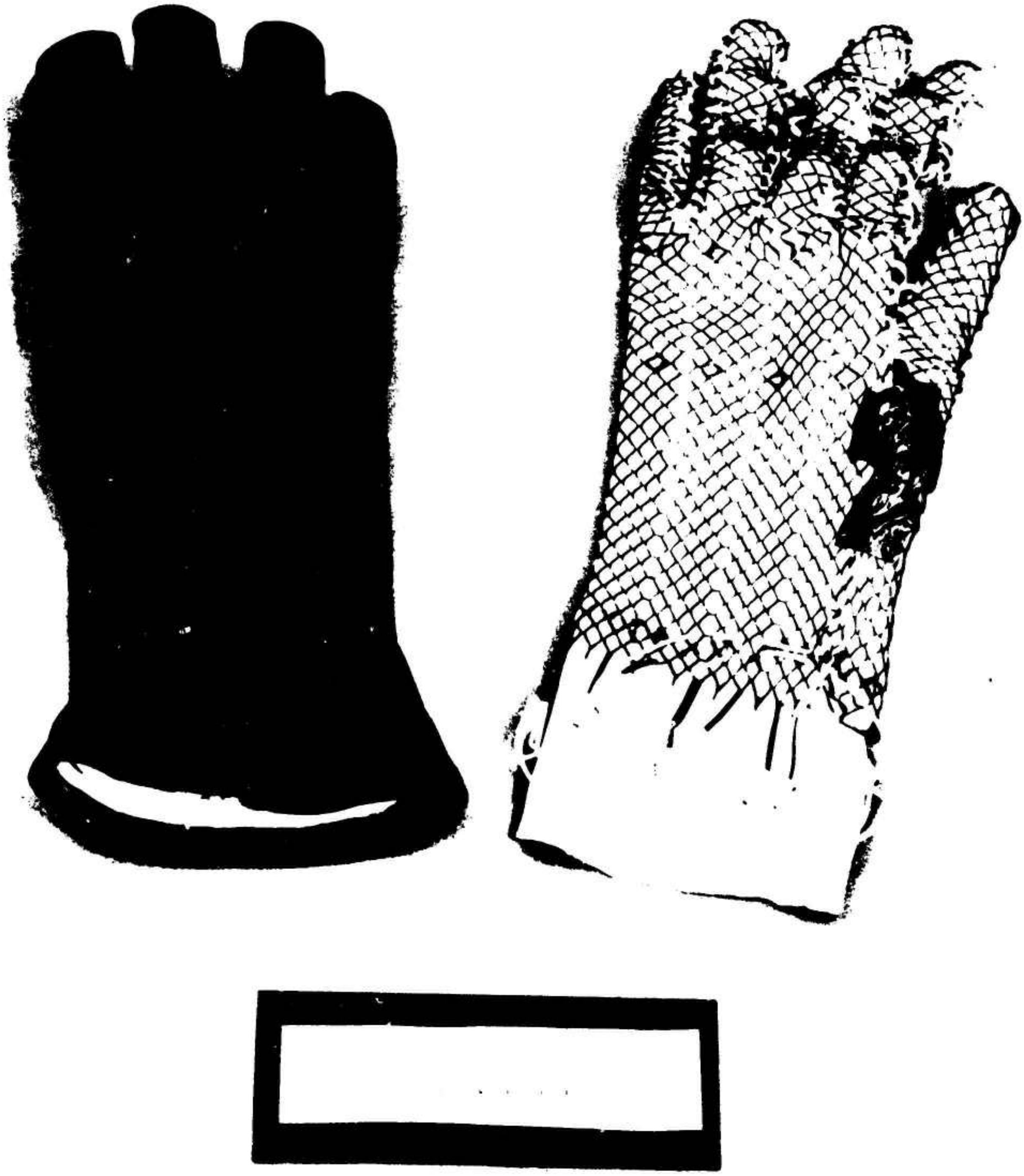












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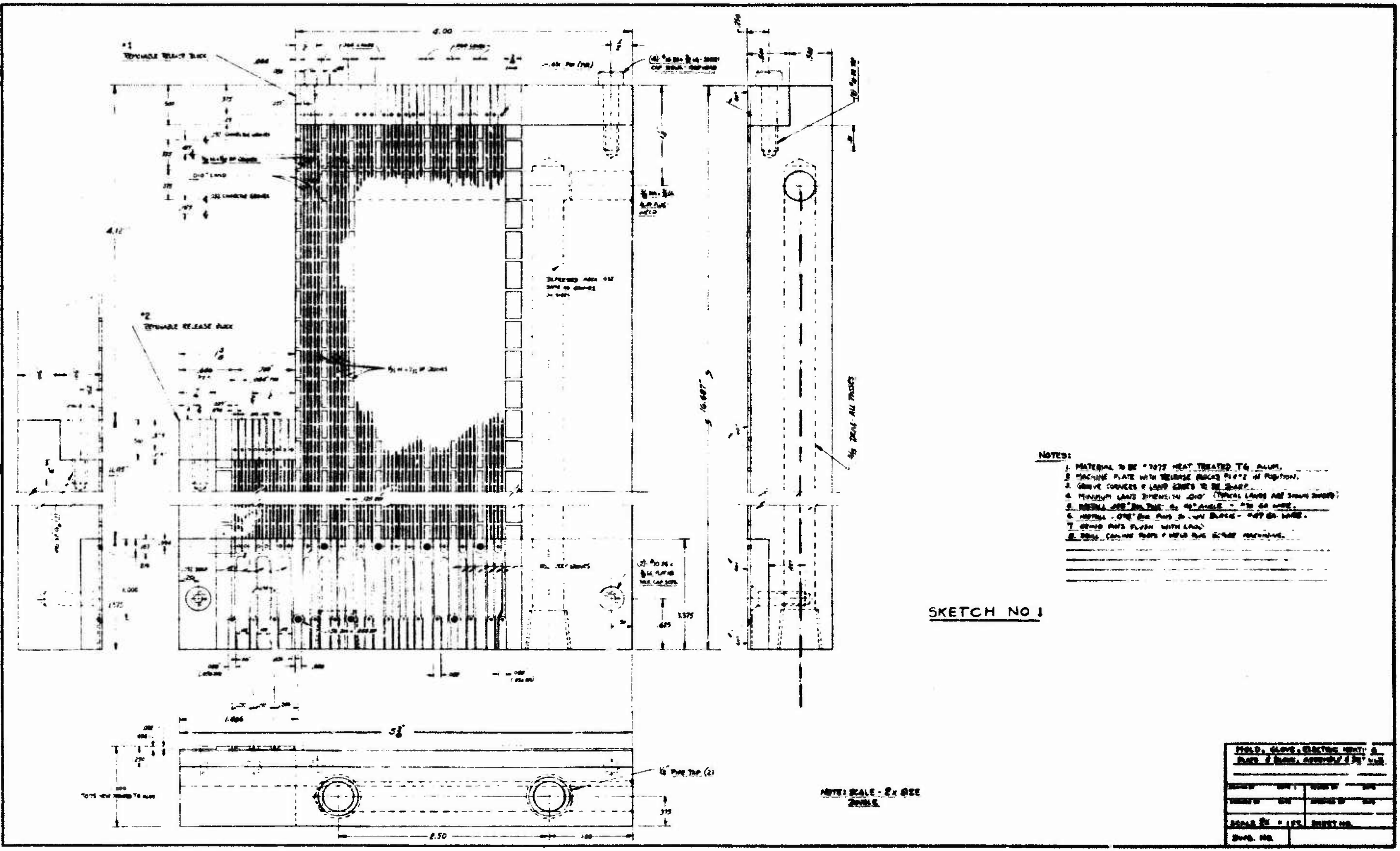

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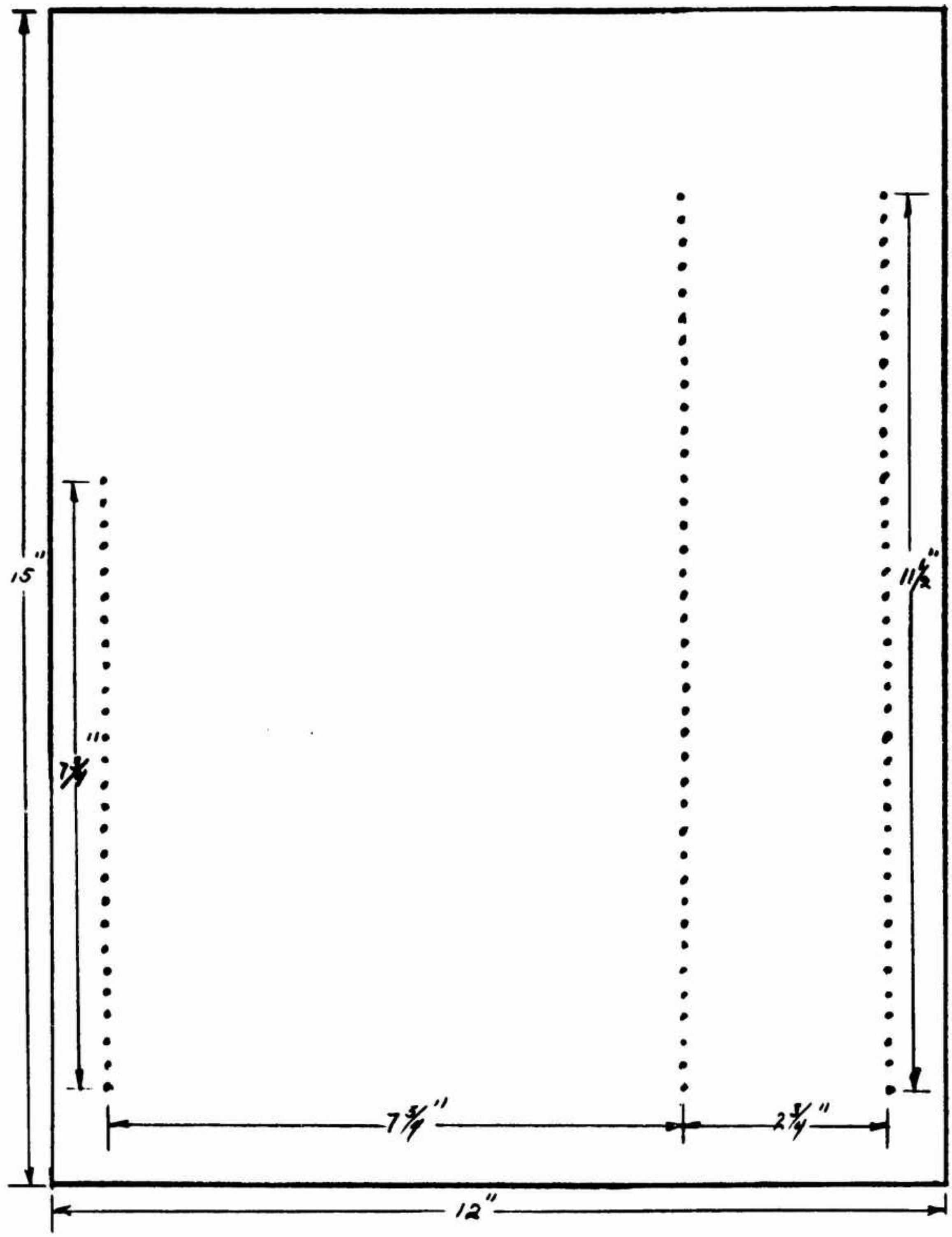
SKETCH NO 2

PLAN VIEW - ANNEALING BOARD
1/2 SCALE



SKETCH NO. 3

RESISTANCE WIRING & LEAD WIRE SCHEMATIC

MACHINE KNITTED CIRCUIT